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U.S. PATENT APPLICATION

FOR

ENGINEERED INTERFACE FOR LOW FLY HEIGHT

INVENTOR(S):
Donald Gillis
Remmelt Pit
Vedantham Raman
Reinhard F. Wolter

ASSIGNEE: HITACHI GLOBAL STORAGE TECHNOLOGIES

SILICON VALLEY IP GROUP, PC
P.O. BOX 721120
SAN JOSE, CA 95172

ENGINEERED INTERFACE FOR LOW FLY HEIGHT

FIELD OF THE INVENTION

The present invention relates to manufacture of disk drive systems, and more particularly, this invention relates to new disk surface properties providing enhanced performance at low fly heights.

BACKGROUND OF THE INVENTION

A magnetic disk drive storage device typically comprises one or more thin film magnetic disks, each having at least one data recording surface including a plurality of concentric tracks of magnetically stored data, a spindle motor and spindle motor controller for supporting and rotating the disk(s) at a selected RPM, at least one read/write transducer or "head" per recording surface formed on a slider for reading information from and writing information to the recording surface, a data channel for processing the data read/written, a positionable actuator assembly for supporting the transducer in close proximity to a desired data track, and a servo system for controlling movement of the actuator assembly to position the transducer(s) over the desired track(s).

Each slider is attached on one surface to an actuator arm via a flexible suspension and includes on an opposite side an air bearing surface (ABS) of a desired configuration to provide favorable fly height characteristics. As the disk rotates, an air flow enters the

slider's leading edge and flows in the direction of its trailing edge. The air flow generates a positive pressure on the ABS, lifting the slider above the recording surface. The slider is maintained at a nominal fly height over the recording surface by a cushion of air.

As recording density and data transfer rate have increased over the past a few years, critical dimensions in the recording device such as track width read and write gap and coil size have decreased accordingly. Also, the fly height between the air bearing surface (ABS) and the media has become smaller and smaller. For reference, recording heads with 40 gb/in^2 products typically have fly heights of about 12 nanometers. Modern heads have even lower fly heights, and fly heights are expected to continue to decrease. This reduction in head critical dimensions and fly height, while beneficial to magnetic performance, also comes with cost on thermal and mechanic reliability. Particularly, with lower fly heights between the head and the magnetic disk during operation of the disk drive, there is an increasing rate of intermittent contacts between the head and the disk resulting in damage to the disk surface and wear on the head elements.

To help avoid the problems caused by intermittent head-disk contact, disks are lubricated during drive build. Although the disk is coated with lubricant during manufacture to protect it from such intermittent contact, during operation of the drive, the lubricant is eventually depleted from the surface of the disk. Because of the problems associated with lubricant spin-off from the disk, a vapor phase lubricant reservoir system has been disclosed as a means for continuously maintaining a uniform lubricant film on the disk. However, as fly heights are reduced, the slider will tend to contact the disk surface and, consequently, the lubricant. It has been observed that interaction between the slider trailing edge and the free lubricant can lead to severe instabilities, causing the

slider to oscillate at its second pitch natural frequency (around 300kHz for currently tested sliders) with an amplitude of more then 5nm. This is a serious problem for reliability purposes. Thus it would be desirable to reduce lubricant induced slider oscillation by improving and stabilizing the clearance between the slider and the disk surface to reduce significant lubricant transfer between the disk and the slider.

Disk roughness also becomes more of a problem at lower slider flying heights. With maximum peaks more likely to protrude into a normal range of slider operation, the probability of unintended and damaging slider/disk contact increases. The risk of damage from these discontinuities is greater at lower slider flying heights. Because of this, disks are being manufactured to have very smooth surfaces. Modern disks have a surface roughness (standard deviation Rq) of about 2-4Å as measured in the 10-100 μm range along the disk surface, and typically have a microwaviness (standard deviation Wq) of 5Å or more in the 100-1000 μm range.

The inventors have found that such smooth surfaces create another problem, that of stiction of the slider on the disk surface. Stiction is the tendency of smooth surfaces to stick together. As the disk rotates, stiction effects during slider-disk contact causes the slider to bounce, resulting in read and write instability. The inventors have found that stiction problems are more prevalent when using disks with low Rq and low Wq.

What is therefore needed is a way to enable reduced fly height while avoiding the hereinabove mentioned problems.

SUMMARY OF THE INVENTION

The present invention overcomes the drawbacks and limitations described above by providing a magnetic disk having a low surface microwaviness (Wq) at a scale of about 200 microns and higher, and a high surface roughness (Rq) at a scale of less than about a length of a pad of a slider carrying a head for writing to the disk.

In one embodiment, the disk has a high surface roughness at a scale of less than about 200 microns. In another embodiment, the disk has a high surface roughness at a scale of less than about 100 microns.

In yet another embodiment, the disk has a low surface microwaviness at a scale of between about 500 and 1000 microns.

In a further embodiment, the disk has a low surface roughness at a scale of about 5 microns or less.

Preferably, the low surface microwaviness is defined by an average standard deviation of about 3 angstroms or less of topographical features of the disk surface at the prescribed scale. Also preferably, the high surface roughness is defined by an average standard deviation of about 4.5 angstroms or more of topographical features of the disk surface at the prescribed scale.

The unique design of the disk surface is very advantageous for use with sliders flying at a fly height of about 5 nanometers or less from the disk surface.

Other aspects and advantages of the present invention will become apparent from the following detailed description, which, when taken in conjunction with the drawings, illustrate by way of example the principles of the invention.

Brief Description of the Drawings

For a fuller understanding of the nature and advantages of the present invention, as well as the preferred mode of use, reference should be made to the following detailed description read in conjunction with the accompanying drawings.

FIG. **1** is a simplified drawing of a magnetic recording disk drive system.

FIG. **2** is a partial top view of the disk drive system of FIG. **1** according to one embodiment of the present invention.

FIG. **3** is a simplified side view of a slider, not to scale, according to one embodiment.

FIG. **4** is a chart illustrating test results of a takeoff pressure test that measures the occurrence of head-disk interactions.

FIG. **5** is a chart illustrating characteristics of a roughness spectrum of several disks over a range of wavelengths.

BEST MODE FOR CARRYING OUT THE INVENTION

The following description is the best embodiment presently contemplated for carrying out the present invention. This description is made for the purpose of illustrating the general principles of the present invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. **1**, there is shown a disk drive **100** embodying the present invention. As shown in FIG. **1**, at least one rotatable magnetic disk **112** is supported on a spindle **114** and rotated by a disk drive motor **118**. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the disk **112**.

At least one slider **113** is positioned near the disk **112**, each slider **113** supporting one or more magnetic read/write heads **121**. As the disks rotate, slider **113** is moved radially in and out over disk surface **122** so that heads **121** may access different tracks of the disk where desired data are recorded. Each slider **113** is attached to an actuator arm **119** by way of a suspension **115**. The suspension **115** provides a slight spring force which biases slider **113** against the disk surface **122**. Each actuator arm **119** is attached to an actuator means **127**. The actuator means **127** as shown in FIG. **1** may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller **129**.

During operation of the disk storage system, the rotation of disk **112** generates an air bearing between slider **113** and disk surface **122** which exerts an upward force or lift

on the slider. The air bearing thus counter-balances the slight spring force of suspension **115** and supports slider **113** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **129**, such as access control signals and internal clock signals. Typically, control unit **129** comprises logic control circuits, storage means and a microprocessor. The control unit **129** generates control signals to control various system operations such as drive motor control signals on line **123** and head position and seek control signals on line **128**. The control signals on line **128** provide the desired current profiles to optimally move and position slider **113** to the desired data track on disk **112**. Read and write signals are communicated to and from read/write heads **121** by way of recording channel **125**.

Referring to FIG. **2**, there is shown a top view of the disk drive **100** of FIG. **1**. The disk drive **100** has a disk pack comprising a plurality of stacked thin film magnetic recording disks **112** attached to the spindle **114** enclosed in housing **204**. Load/unload structure **206** is fixedly secured to the base plate **508** of the housing **204** of the disk drive at the outer perimeter of disk pack. A rotary actuator assembly comprises a plurality of actuator arms **210** each supporting a slider **113** adjacent to a disk **112**. Each actuator arm **210** suitably has a protrusion or tab **212** at its distal end for engaging a ramp **214** of the load/unload structure **206** during load/unload operations. The vapor phase lubricant reservoir system **131** is positioned in the housing **204**. A vapor phase lubricant reservoir system **131** such as the systems described in U.S. Pat. No. 4,789,913 and/or U.S. Pat. No. 6,580,585 can be implemented. These patents are incorporated herein by reference.

FIG. **3** illustrates a slider **113** according to one embodiment. As shown, a protruding pad **302** is positioned above the read/write elements **304**. An overcoat **306** of carbon, SiN_x, etc. is formed over the entire structure.

The above description of a typical magnetic disk storage system, and the accompanying illustration of FIGS. **1-3** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

The inventors have characterized several magnetic recording disk surfaces designed for low flying heights, and have found that that a "hybrid" characteristic—higher roughness at the lower wavelength and lower microwaviness provides the best performance. In contrast, and counterintuitively, disks that have lower roughness at the lower wavelength and lower microwaviness (i.e., smoother disk surfaces) provide the worst performance.

FIG. **4** illustrates results of a takeoff pressure test that measures the occurrence of head-disk interaction and, consequently, the likelihood that such interaction will lead to issues relating to servo problems, repeatable run out (RRO) issues, etc. In FIG. **4**, all measurements were taken with same slider flying at about 5 nm, but on four disks having different surface properties: 1) high Rq, low Wq; 2) high Rq, low Wq; 3) high Rq, high Wq; 4) low Rq, low Wq. Rq is measured at a scale of less than about 200 microns, which is about the size of the pad on the slider used. Wq is measured at a scale of about 200-1000 microns. Lower Rq and Wq values correspond to smoother surface properties.

With continued reference to FIG. **4**, as ambient pressure in the drive is reduced (X axis), the slider flies at lower and lower fly heights. Accoustic emissions (AE) are used to

measure the slider-disk contact, in this case by an AE measuring device placed on or near the slider. A desirable AE count is less than about 0.02 to avoid stability issues. For instance, if too much slider-disk contact occurs, the slider tends to bounce, which leads to instability.

Intuitively, smoother disk surfaces should allow the slider to fly closer to the disk surface without interference. However, what has been found is that once a certain smoothness has been reached, the attractive forces between the disk and slider come into play to cause stiction problems. As shown, at lower surface roughness and microwaviness, the slider contacts the disk surface rather quickly upon a drop in ambient pressure. The inventors have found that the figure of merit attribute for low flying disk surfaces is (a) higher roughness and (b) lower microwaviness in the realm of low flying heights, typically less than about 5 nm of mechanical spacing.

Modern disks have an Rq of about 2-4Å, and a Wq of 5Å or more. The inventors have found that the most desirable disk surface properties are an Rq of 4.5Å and higher, and the Wq reduced to about 3Å or less for sliders of about 500 μm in length, the sliders having pad lengths of about 200 μm. These values generally apply to all disk substrates, e.g., glass, Al-Mg, polymer, etc. Also note that pad sizes are also being reduced to assist in reducing contact area of the slider with the disk. Accordingly, the desired disk surface properties may scale with the pad size.

According to one preferred embodiment, the disk surface has a low micro-waviness at a scale of 200μm-500μm and more for fly height modulation (this length scale is defined by the slider full length), low roughness at a scale of 5μm or less for surface integrity such as corrosion and defects (this length scale is defined by the

magnetic domains TPI and BPI), and high roughness at a scale of 10 to 100μm to minimize friction between the slider ABS pad and the disk during accidental contact (this length scale is defined by the ABS pad size).

The characteristics of the roughness spectrum over a range of wavelengths are shown in FIG. **5**. The roughness spectrum was measured by an Optical Surface Analyzer (OSA) model TS5100, manufactured by Candela Instruments. The OSA uses a light deflection technique to measure topographical features on the disk surface. The Fourier Transform obtained by an FFT algorithm, is a measure of the surface properties of the disk.

The roughness spectrum of FIG. **5** is a Fourier transform of four disk surfaces: 1) high Rq, low Wq; 2) high Rq, low Wq; 3) high Rq, high Wq; 4) low Rq, low Wq. The smaller the wavelength, the smaller the amplitude of the surface feature. As shown, at the 1000 micrometer wavelength, it is seen that almost all disks have the same amplitude in terms of waviness deviation. However, at 100 micrometers (about the size of the pad), differences can be seen between the various surfaces. The desired disk surface properties have low amplitude at higher wavelengths, but have a higher amplitude at a lower wavelength to avoid the stiction problem.

The inventors also define a scale of the size of the ABS pad. This 10-100μm ABS pad scale and the 500μm-1000μm fly height modulation scale can both be measured on an OSA. The trace analysis gives the following numbers (this is the same information as the plots in FIG. **5**):

Table 1

Type AFM	Rq	microXAm Wq	Touch Down Height (from Pressure)
low low	0.13 nm	0.3 nm	4.3 nm (-14 kPa = 0.86atm)
high high	0.16 nm	0.4 nm	3.9 nm (-22 kPa = 0.78atm)
high low	0.18 nm	0.35 nm	2.75 nm(-45 kPa = 0.55atm)

To create a disk surface having the desired combination of high Rq and low Wq, the designer can adjust the manufacturing parameters to obtain the desired properties. One skilled in the art will understand how to obtain the surface properties defined herein and so no further discussion of disk manufacturing will be provided.

The new structures described herein provide the following tangible benefits:

(a) Improved yields: For sliders with mechanical fly heights under 5 nm and approaching contact recording, significant yield improvements can result due to the reduced likelihood of slider-disk contact.

(b) Better clearance: The new disk surface should provide about 2 nm improved clearance based on TOP info with disks that have the attributes outlined in the disclosure. This is important when interfaces are flying at or around 5-6 nm.

(c) Slider bounce (stiction due to the smooth surface) for interfaces in contact is significantly reduced. The advantage could be as much as 50% or more over disks with low Rq and low Wq, and/or high Rq and high Wq.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Thus, the

breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.